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Geography and 'thing knowledge': instrument epistemology, failure, and narratives of nineteenth-century exploration

The paper examines the relationships between instrument epistemology, failure, and textual authority with reference to the place of scientific instruments in published narratives of nineteenth-century exploration. The paper draws upon Baird's work on instrument epistemology and 'semantic ascent' and Gooday's work on failure and on the morality of measurement. Its empirical focus comes from examination of RGS manuscript AP 52, a list of instruments provided by the RGS for thirty-one explorers in the period *c*.1877 to *c*.1883. Instruments are shown to (do) work in the field, even as explorers admitted to failure, in the devices and in themselves. Narrative accounts, often compiled elsewhere, obscure the contingent nature of instruments' use. The findings have implications for assessing the agency of instruments in exploration, instrument epistemology and narrative inscription, and for understanding failure in geographical work.

Key words exploration; failure; instrument epistemology; instruments; publication; thing knowledge

1 | INTRODUCTION

> That the history of science and increasingly the history of modern culture is indeed a history of instruments and their intelligent – and sometimes not so intelligent – use should be well known. We need to take notice (Baird, 2004, p. xv).

This paper examines the place of scientific instruments in published narratives of nineteenth-century exploration and the relationships between instrument epistemology, failure, and textual authority. Studies of the relationship between exploration and authorship identify several stages between the act of exploration and the production of printed narratives about it. These involved in-the-field note taking and in-situ alteration; later redaction elsewhere; post-exploration appeals to memory when in-situ writing proved inadequate; and the role of editors and publishers in revising the content, even the chronology of exploration, to suit perceived audience demand (Bourguet, 2010; MacLaren, 1992, 2011). Others have addressed the nature of exploration and the complexities of bringing exploration into print (Driver, 2004; Keighren, Withers and Bell, 2015; Kennedy, 2014). For Craciun, the term 'explorer' is a nineteenth-century back-formation, applied in the asynchronous construction of authorial identity (Craciun, 2011, 2016).

In contrast, we know little about how explorer-authors, dependent upon instruments such as chronometers, sextants and barometers to find their way and measure the phenomena encountered, used those instruments. In one sense, this is about the operation of instruments in exploration, their reliability and capacity to produce meaningful results – the working of the things themselves. In another, it is about the place afforded instruments in authors' accounts of what exploration involved – how explorer-authors wrote about instruments. Explorers should have invested importance in them: the provision and proper use of scientific instruments was emphasised in guides to scientific method (Jackson, 1841; Herschel, 1849; Driver, 1998; Withers, 2013). Wess's (2017) important survey of instrument provision by the Royal Geographical Society (RGS) shows that the society supported 436 expeditions in the century from 1830. With others (Rae, Souch and Withers, 2015; Wess and Withers, 2018), she has documented regional variations in where RGS instruments were at work (chiefly in African exploration), and shown how a culture of instrument provision and training was slow

to emerge. Of a few explorers, it is possible to document instruments at work and how that work appeared, or not, in subsequent narratives of exploration (Wess and Withers, 2018, pp. 10–13).

Yet not all exploration was a success. Do narratives of exploration include discussion of instrumentation? If the devices failed (many did), how was failure managed in situ and dealt with in narrative accounts that purported to be reports of geographical achievement? How in historical context can we take note of the work that instruments did and give them due recognition as agents of – and, possibly, hindrances to – exploration and publication?

The paper addresses these and related questions in three parts. The first briefly reviews work in geography and related subjects in which instruments have been of central concern before turning to Baird's arguments on instrument epistemology and 'thing knowledge' (Baird 2004) and to Gooday's on failure and the morality of measurement (Gooday, 1998, 2004). In his use of the term 'instrument epistemology', Baird examines the different work performed by instruments and the relationships between instrumentation, measurement, and inscription. The epistemological work done by instruments is, he argues, occluded by the reduction of 'thing knowledge' to word knowledge, what Baird terms 'semantic ascent' (Baird, 2004, p. 8). For Gooday, measurement and inscription carry moral significance: as, variously, trust in the device, in the user, and in the resultant data when instruments failed. These arguments, I suggest, can extend understanding of the place of instruments in geography and the connections between instrument work, exploration, failure, and narrative inscription.

The second tests these claims through analysis of Royal Geographical Society manuscript AP 52. Produced in association with administrative changes in the RGS which aimed at a more 'scientific geography', this document enumerates the instrumental and exploratory activities of thirty men and one woman between *c.*1877 and *c.*1883. The manuscript has been

noted elsewhere (Rae, Souch and Withers, 2015, pp. 155–156; Wess, 2017, p. 56), but has not been subject to detailed scrutiny until now. Its examination allows insight into who the RGS supported with instruments, where they intended to use them, and which instruments were used. A note on method is pertinent. Of the thirty-one listed individuals, seventeen published in RGS journals: twenty-four papers in total. Two explorers additionally wrote books. This cumulative output was read for remarks upon instruments. The JMS (journal manuscript) material for each of the twenty-four articles was then scrutinised. This contains referees' reports upon submitted articles. The reports include remarks about the accuracy of the work, authorial and instrumental competence, and any redaction proposed prior to publication. Correspondence block (CB) files – letters to and from RGS officials – were appraised for the identified individuals. This record linkage allows insight into instrument use, and how authors wrote about their use of instruments.

Part three considers the implications of examining connections between instrument epistemology, failure, and narrative textuality. These include giving greater attention to instrument epistemology in understanding the doing of geography, and questions surrounding failure (for a recent overview of the topic, see Carroll et al, 2017). Failure has received some attention in geography. It has been addressed for the expectations of geographers undertaking ethnographic work (Harrowell, Davies, and Disney, 2018). There is a strand of biographical writing that associates specific explorers (Franklin, Livingstone, Scott) with failure (see Bloom, 1998), even seeing heroic failure as quintessentially British (Barczewski, 2015). The failure of instruments in use, however, is not a matter of dysfunctional technology, but of the working relationships between users, the devices and the purposes to which the work was put. This paper addresses failure's more quotidian expression, its material form and epistemological implications and the need to think further about it in historical and textual context.

2 | INSTRUMENTS AT WORK – TOWARD AN INSTRUMENT EPISTEMOLOGY

In geography, the use of scientific instruments – chiefly hand-held or manually operated devices for measurement – was important in the subject's empirical development in the nineteenth century, in association with instructional guides on how to observe and what to record (Driver, 1998, 2001; Rae, Souch and Withers, 2015; Withers, 2013; Wess, 2017; Wess and Withers, 2018). Humans even regulated themselves, and their horses and wagons, to become instruments (Raj, 2002; Driver, 2001; Fleetwood, 2017). Nineteenth-century terrestrial exploration had maritime parallels in new systems of measuring extreme weather (Naylor, 2015). The oceanographic sciences, dependent initially upon a variety of instruments for navigation and depth sounding, later developed specialist sub-surface devices (Millar, 2013; Naylor and Ryan, 2010). Aerial photography, an instrumental accomplishment used in archaeology and military geography, was forerunner to satellite remote sensing (Collier, 2015). Other works speak to the presence of scientific instruments in global geopolitics (MacDonald, 2015; Shaw, 2016). Taken together, these studies identify the problems of measurement and instrumental fallibility in spatial inscription.

Historians of technology have examined particular instrument types (Dunn, 2009), instruments as quotidian devices measuring geophysical phenomena during terrestrial exploration (Dunn, 2015; Goodman, 2016) and hydrographical survey (Barford, 2017), or enumerated technological developments in relation to particular needs (Bennett, 1987) and periods (de Clerq, 1985; Turner 1983, 1991). Historians of science – some initially cautious about what, exactly, a 'scientific instrument' was (Warner, 1990; van Helden and Hankins, 1994) – have re-engaged with instruments: with their use (Taub, 2011); their biographies as scientific objects (Daston, 2000, 2004); with the epistemological consequences of breakage (Baker, 2012; Schaffer, 2011); and how they mobilize 'data' into commonplace 'fact' (Latour, 1987, 1999, pp. 24–79; Rheinberger, 2011).

Together, this work has exposed how much more there is to know about the role played by instruments in the doing of science and of geography. Instruments are not inert. Even 'standard' devices work in different ways. Disciplines ascribe significance to instruments in distinct ways: some, biology for instance, associate professional expertise with operating devices that trace, record, and thereby 'prove' the presence of otherwise invisible natural phenomena (Gooday, 1997). Instruments depend for their efficacy upon users' interpretation of the results, often in relation to a graduated scale as surrogates for particular phenomena (temperature scales in thermometry for example: Chang, 2004). Instruments confer credibility and invoke trust in the explorer-author's resultant truth claims (Shapin, 1994; Withers, 2018).

Yet the units used in instrumentally mediated enquiry, whether in the micro-worlds of natural history and thermometry, or in global metrology and terrestrial survey, are neither standard nor consistently used (Schaffer, 2017; Withers, 2017). Instruments break, go slow, resist calibration. Ought we – and, if yes, how – to trust those narratives consequent upon instruments' usage when the devices used in constituting those narratives could be 'easily cracked' (Schaffer, 2011). Do we place trust in the instrument, in the measurements produced, or in the moral authority of the user? (Gooday, 2004). There is, too commonly perhaps, an unexamined sense that instruments and the rhetoric associated with them – 'greater accuracy', 'increased resolution' and so on – always and straightforwardly improve over time, and, almost, do so of themselves. The history of science as, foremost, a history of theory has predominated over historical accounts of practice in which instruments might 'speak' for themselves. For all these reasons, 'we need to construct an epistemology capable of including instruments' (Baird, 2004, p. 5).

Instrument historians posit four categories in terms of a social hierarchy of use – physical and analytical instruments (used by research scientists), professional instruments (employed by surveyors, for example), teaching instruments (to demonstrate the action of something),

and recreational instruments (for amusement or instruction) (Turner, 1983, p. 18). Baird distinguishes between different scientific instruments on epistemological grounds: models, which perform to produce representations; devices that create a phenomenon; and measuring instruments. Models can be judged 'in terms of the virtues and vices that are used to assess theoretical representation: explanatory and predictive power, simplicity, accuracy, and so on' (Baird, 2004, p. 12). Instruments that create phenomena provide 'working knowledge', a form of knowledge as effective action wherein the action has been separated from human agency and built into the reliable behaviour of an artefact because the instrument is designed to do something in a particular way: it may be said to (do) work if it does that something successfully and reliably. Measuring instruments are a hybrid of models and devices that create a phenomenon. This is because measurement presupposes its representation, and because they have to do something reliably and consistently: 'the instrument must yield outcomes that are the same or can be understood to be the same given an analysis of error' (Baird, 2004, p. 12). Baird calls this integration 'encapsulated knowledge', 'where effective action and accurate representation work together in a material instrument to provide measurement' (Baird, 2004, p. 13).

Understood thus, instrument epistemology moves enquiry beyond simple typologies, of either instrument or user. It invites consideration of the relationship between epistemology, narrative and the technologies of production but does not suppose the outcome: 'the more basic point here is that the material realm provides a space within which work can be done' (Baird, 2004, p. 10). It allows us to test Baird's notion of 'semantic ascent' (Baird, 2004, p. 8), the primacy of narrative accounts in which the work of words displaces the work of instruments. Baird is not alone, of course, in addressing the materiality of knowledge's making – Latour's attention to non-human actants, experimentation, and laboratory life testifies to this (Latour, 1987; Latour and Woolgar, 1979). Attention in these ways to

instruments 'differs profoundly from the rationalist notion that experiments and instruments are simply the mechanical implementation of previously laid theoretical plans' (Lenoir, 1997, p. 9).

A brief illustration will help substantiate these points. Studies of instrumentation in Arctic exploration and geomagnetic survey have revealed the testing and use of the dipping needle and different types of compass and the problems faced by their operators in producing 'encapsulated knowledge' in environments where trust and credibility had constantly to be earned (Dunn, 2015; Goodman, 2016). The ships under John Ross on his 1818 Arctic voyage carried seven types of magnetic compass. Guidance on their use was clear (Kater 1818). The crews found the different types worked differently well: a consequence of natural variation in magnetic intensity, the skill of their operators, and the positioning of the instruments on the vessels where the influence of ship's iron produced irregularities of reading. On-board in-situ investigation – and its consequent inscription in log books – was thus a matter of accommodating failure and tolerating error, facts admitted to by the explorers (Dunn, 2015). In appendices to his post-voyage narrative, Ross reported upon the performance of the different instruments in order to reassure readers of the importance of the voyage and the instruments' utility in securing its findings (Ross, 1819, pp. xvii–xcix, cxxiv–cxxxii). Where the appendices admitted to failure (of some devices) in a narrative otherwise scientific and successful, Ross used his preface to emphasise the voyage's overall significance: 'If I have thus missed to give entertainment, I, however, trust, that I have diminished nothing from the utility of the statements to seamen, nor their authority to geographers' (Ross, 1819, p. iii). For Ross, instruments were necessary to his credibility on the voyage and, later, to his status as explorer-author. The instruments' performance was acknowledged in helping promote a 'more accurate' geography, yet the instruments central to that undertaking were displaced in written accounts of it (a feature common in Arctic exploration: Levere, 1986).

This example highlights the significance of prior instruction, the a priori role of theory and the twin geographies of effect: what did instruments do; how was it written about? Considered thus, instruments – and the material and textual spaces they inhabit – no longer remain 'simply an extension of theory, a mere supplement, useful for exteriorising an ideal meaning contained within theory' (Lenoir, 1998, p. 6), but become things with stories to tell.

3 | INSTRUMENTS AT WORK – IN THEORY, IN PRINT: MS AP 52

What is now MS AP 52 is associated with initiatives implemented by the RGS from the mid-1870s to improve how the Society managed its instrument collection and trained would-be explorers (Wess, 2017, pp. 56–57). Revisions to the instruments committee sought greater clarity in instrument management. A fund for 'the promotion of special scientific branches of geography' was established in 1876. In 1877, a scientific purposes committee was set up to administer the fund, under the direction of Clements Markham. An instrument instructor, John Coles, was appointed in 1877. From January 1878, a new edition of the Society's *Hints to Travellers* (first published in 1854) was begun in order to guide those intending to use instruments (Jones, 2005, pp. 319–320; Rae, Souch and Withers, 2015; Wess, 2017).

It is difficult to establish a more exact provenance. The manuscript – reproduced here as Table I – is untitled. The first date of entry is 1877. It is without authorising mark or authorial signature. The date '7/6/1883' appears to its foot, a date consistent with the year given for the last of the explorers listed. These facts are important. The scientific purposes committee, in May 1879, prepared a 'Memorandum on a plan for training travellers to make useful scientific observations'. From June 1879, in its report to council, the committee identified nine categories of persons who would benefit from RGS training: army and navy officers; clerks employed in merchants' houses; planters and settlers; engineers; missionaries; colonial officials; collectors; sportsmen; and 'ordinary travellers' (Jones, 2005, p. 319).

<Table I about here, full page(s), landscape style>

Manuscript AP 52 echoes these concerns but predates them by about two years. Coles was map curator and instrument instructor from 1877 – not, as Jones states, from 1881 (Jones, 2005, p. 320). He taught several of those whose names appear on MS AP 52 and did so before the May 1879 'Memorandum' of Markham's scientific purposes committee and its June report. MS AP 52 was, almost certainly, initiated and managed at Coles' behest. The manuscript incorporates the hands of at least two different 'authors', notably in the 'Remarks' column and mainly in Coles' handwriting. Surviving records do not indicate why it ceased in June 1883 and why there are no comparable listings for other dates. Coles, with others, was much involved in 1882 and 1883 in preparation of a fifth edition of *Hints*, a work of major revision in which Coles wrote the expanded sections on surveying (Rae, Souch and Withers, 2015, 149; Wess, 2017, 121). This work, which was an important advance upon earlier editions and a marker of the society's developing professionalism (Jones, 2005, 321; Wess, 2017), may have distracted Coles from more mundane record keeping and instructional responsibilities.

The results following analysis of this source are in two sections. The first looks at the explorers, their training, and the instruments used. The second examines the relationship between instrument epistemology and exploration narrative and considers Baird's idea of semantic ascent in terms of what explorers wrote about instruments and their use.

3.1 | Explorers and instruments at work

The thirty-one individuals involved in exploration over this six-year period were active in nineteen locations. Africa, particularly East Africa, was the subject of eleven explorations, three by Joseph Thomson. Asia was the location of six expeditions. Two polar endeavours were supported: Markham's Barents Sea voyage (Markham, 1879) and Dawson's

geomagnetic enquiries in the Canadian Arctic as part of the International Polar Year 1882–1883 here described as the 'Circumpolar Expedition' (Table I). This emphasis upon Africa, its topographical survey and geographical debate over the interior disposition of mountain ranges and lakes, is consistent with what others have shown of British geographical exploration at this time (Driver, 2001; Dritsas, 2011; Wess, 2017, pp. 66–70).

The instruments provided – commonly, sextant, artificial horizon, boiling point thermometer (used in hypsometry and topographical survey to calculate height), prismatic compass – all appear as essential items in guides such as *Hints to Travellers* (1854) and Jackson's *What to Observe* (1841). The purpose of these 'professional instruments' (to use Turner's typology) and of instructions on their use was 'limited to surveying and mapping, including the fixing of positions by astronomical observations'.[1] Work with the sextant, the artificial horizon and the prismatic compass was, for every traveller, 'the groundwork of the acquirements which he [sic] ought to possess'.[2] Training in instruments aimed at instructing users in order that they might produce a map or correct the work of others. Where others have looked at Coles' work in revising Hints (Rae, Souch and Withers, 2015) and at trends over time in the RGS's management of instruments (Wess, 2017; Wess and Withers, 2018), this papers offers a detailed understanding of the experiences of a few explorers, the instruments they used, and how they wrote about those instruments in later narratives.

Coles' first pupil was the Rev. J. T. Comber of the Baptist Missionary Society (Table I). By early 1880, Coles had ten men under training. Instruction included 'calculating heights by Barometric differences, . . . Plain trigonometry, . . . Finding the latitude and Longitude' by different methods.[3] His description of his students allows cross-reference against MS AP 52: 'four are members of the medical profession, one being the Government botanist in Afghanistan [Surgeon Major James Aitchison; the other identified doctors being Peden and Southon], the other three are missions [missionaries] to China and Africa [Comber, W. P.

Johnston, and Stewart], one is a Civil Engineer in command of [the] military expedition to the Upper Congo [McCall] , one [Phipson-Wybrants] is an officer who has served with the rank of Captain in the army, and who is about to proceed to East Africa, another is a civil engineer who is preparing himself for foreign service by receiving instruction in the methods of fixing positions by astronomical observations [Colquhoun], and my other pupil is about to re-visit Armenia and Persia in which countries he [E. Delmar Morgan] has already spent some time'.[4] Even experienced Africanists like Joseph Thomson and Verney Lovett Cameron received instrument training. The RGS was insistent on this: Thomson's East African Expedition delayed its departure in 1883 in order that Thomson (who had earlier been to Africa with the Society's instruments) could receive additional instruction from Coles.[5]

That Markham's committee exercised a degree of control over the nature of the training, emphasising surveying, mapping and fixing astronomical positions, is clear from surviving minutes.[6] It is clear, too, that if 'the bestowing of instruments for loan can be taken as a criterion for the success of the training' (Wess, 2017, 132), instrument training was no guarantee of success: Keith Johnston, Mullens, McCall, Phipson-Wybrants, and Appel each died undertaking exploration (within the dates of the manuscript): Comber and Stewart soon after. For instruments similarly, working lives could be abruptly halted. In twenty of the thirty-two events of exploration, instruments did not return: either they were still in use (in twelve instances), because their users returned but the instruments did not, or for other undisclosed reasons (Table I). In two cases (Delmar Morgan and Aitchison), borrowed devices were returned damaged or broken. This evidence can be supplemented using RGS manuscript ledgers 'Instruments Lent to Travellers' and 'Catalogue of Instruments'. For the period after *c.*1860, these itemise, respectively, which explorers borrowed which instruments, where the intended exploration was to be undertaken, and, for several devices, a brief 'life history' of the instrument. All the individuals listed on MS AP 52 (Table I) are enumerated,

some like Joseph Thomson more than once.[7] Space precludes assessment of each individual listed, but a few examples illustrate the instrument's mobility, repair, and repeat circulation. One of the two watches purchased for Comber 'for use in Congo Region, Oct.1879' (and returned to the RGS following his death) went to work in Canada, Guatemala, and Central Africa again, before being returned, broken, in 1896. Repaired, it formed part of expedition equipment in Abyssinia in 1898 before being 'lost from the train on way to Khartoum' the following year.[8] The prismatic compass loaned to Joseph Thomson in December 1882 for his Kilimanjaro Expedition returned to the RGS in October 1884. It was again in East Africa with Last's East Africa Expedition (though not listed as such in MS AP 52: see Table I) from where it returned, broken, in November 1887. Repaired, it later headed to Central Africa, before being lost in Morocco in 1888.[9] This evidence allows us to make two points. First, some would-be explorers were permitted to borrow instruments before training was complete.[10] As Wess notes, the fact that 'status could subvert the efforts to professionalise the Society . . . . undermined the value of the training' (Wess, 2017, 137). Second, several of those persons here listed used instruments previously damaged elsewhere, and repaired before being used again.

In sum, the individuals and instruments recorded in MS AP 52 were at work across the world, with an emphasis on East Africa. Their activities reflected RGS imperatives: survey, accurate topographic measurement, mapping. Most of those listed received instruction prior to departure. Several of the instruments issued had an earlier 'life geography' that embraced moments of disrepair. This is not to see any later failure as simply consequential upon technological breakdown when, as I shall show, unreliability and inaccuracy were, often, understood as part of the work that instruments were said to do. Nor is it to see failure as simply that of the instrument: 'states of disrepair refer simultaneously to tools and humans that interact with them and each other' (Schaffer, 2011, p. 708: on this for African

exploration, see Fabian, 2000). It is to emphasise, following Baird, the need to look harder at what work instruments did, and how. If 'The materiality of instruments only surfaces in their making and breaking' (Baird, 2004, p. 146), and issues of repair and maintenance are central to what things do (Graham and Thrift, 2007), then examining the role of instruments in exploration and in accounts of exploration is important, not least when the devices did not work as they should.

3.2 | Instrument epistemology, trust, and written testimony

Instruments feature in twenty of the twenty-four journal articles produced by the explorers listed in MS AP 52. Two principal themes emerge in assessment of this material: breakage and failure and what, following Gooday (2004), we can think of as the moral bases to measurement in instrument epistemology; and, post facto, the correction of instrument work in published narratives.

Failure, accuracy and the morality of measurement

Remarks about the quality of observations and the resultant inaccuracy of related measurements are often prefaced by reports of breakage. Henry Forbes's instruments failed in a cyclone in January 1876: 'To what distance the barometers fell it is impossible to tell, for the mercurial was broken, and the aneroids when once they had fallen below 27½ inches suddenly ceased to register, and to this day stand mute witnesses of the strain they endured' (Forbes, 1879, p. 781). He later confessed, in private correspondence, to completing the map without use of the instruments.[11] Forbes' refusal to make use of the RGS's instruments led one referee of his work to reduce a submitted paper to a short note.[12]

Based on his experiences around Lake Nyassa, and in contrast to Forbes, James Stewart understood the value of instrumental work in establishing exploratory facts. Different devices

functioned differently well, however, in different geographies: of barometers, he noted that 'It is well known that the barometer in tropical countries is not subject to such rapid changes as in northern latitudes. . . . The barometer is therefore of little use as a weather-glass, but on the other hand it is more serviceable for geographical work in the measurement of mountain heights' (Stewart, 1881, pp. 259–260). Thomson and Southon among others confirm this view (Thomson 1880a, p. 118; 1883, p. 549; Southon, 1882, p. 548). Where barometers were not used (or, sometimes, to corroborate them), boiling point thermometers were employed to measure height, partly to compare different instruments of the same type, partly to calculate the mean of several readings as the basis to claims of topographic accuracy. Sextants were used to take lunars to ascertain latitude and longitude, watches to calculate longitude. During his 1881 exploration, Henry O'Neill, Britain's Consul in Mozambique, was, at his unknown location furthest west, 'anxious to fix its longitude and also to rate my watch'. 'Observations for the latter gave me the same rate, to within four hundredths of a second per day, as that obtained before leaving the coast, so I hope the longitudes by watch obtained up to this point may be fairly reliable' (O'Neill, 1884, p. 636). As O'Neill later observed:

> I need hardly point out to any reader . . . the extreme difficulty, even under favourable conditions, of accurately fixing the longitude of any place upon the earth's surface. This difficulty is, of course, especially felt by the traveller in an uncivilised and unexplored country. He has with him instruments which, however perfect of their class, have, perforce, been selected for other considerations beyond those of extreme and delicate accuracy. They have had to be portable, as simple as possible in design, and capable to a certain degree of adjustment in other hands besides those of their makers, and capable also of withstanding great variations of temperature and

> atmospheric humidity, and sustaining a certain amount of rough usage (O'Neill, 1885b, p. 428).

Further, 'it is only by the closest attention to his instruments, and careful judgement in the bodies he selects for observation, that even a moderate degree of accuracy can be obtained'. The sextant must not only 'be carefully handled, but its numerous and varying errors closely watched and noted'; 'chronometers must not only be carefully carried and subjected to uniform treatment, both when in motion and at rest, but their rates verified and checked by repeated observations for time. If this not be done, all chronometrical observations for longitude may be worse than useless' (O'Neill, 1885b, pp. 428–429).

For O'Neill, accuracy followed from the number of measurements and comparison of results between instrument type: 'There is no better means of eliminating the numerous errors – personal as well as instrumental – inseparable from work under such conditions, than by the careful accumulation of a mass of observations of different class which should be absolutely independent of one another' (O'Neill, 1885, p. 429). It is clear, too, that the fact of error – occasioned by the failure of the device to be sufficiently robust – was tolerated in reporting what the instrument did: that is, accuracy was always relative, measurement a moral judgement of the degree to which, and how often, devices did not function as they should (Gooday, 2004).

In Baird's terms, instrument epistemology foregrounds the work of instruments in generating an end product. Instruments effect representation – here, commonly, a map (one or more maps appear in twelve of the twenty-four papers published in RGS journals). They do not create a phenomenon, but, rather, collect data – 'traces' – later transformed into print (Rheinberger, 2011). For the devices of measurement at work, their function was to provide accuracy with respect to physical features – height, distance, longitude and latitude, and so on

– in order that both the explorer then, and later readers, should know what was where and what its dimensions. Such work involved tolerance of instrumental error, operators' recognition of the contingency of measurement and, for men like O'Neill, accumulation of sufficient data to mask instrumental variability. Others were equally prepared to work with instruments that faltered and to accommodate results of varying accuracy, even to have their capacity as explorers, and, later, authors, diminished in consequence. The Rev. Comber admitted that his longitude readings could not later be corroborated because he allowed his half-chronometer 'to run down'.[13] Delmar Morgan's 'misfortune' in breaking his thermometer put an end to his observations upon thermometry (Delmar Morgan, 1884, p. 187). Keith Johnston's barometric observations – and topographic readings – were interrupted as he turned to his second 'George's barometer' (see Table I), the first having broken en route from the coast (Johnston, 1879, p. 546). Perhaps justifying his later instruction by Coles, Joseph Thomson confessed in 1879 to limited ability with instruments and so, with 'apologetic remarks', sought the tolerance of others: 'I am sorry to say that I have been unable to master the difficulties of the sextant and artificial horizon, and consequently I have been compelled to depend upon the compass. But in protracting my route, I have taken every care, and hope to be found not very far wrong when some competent person, at a future date, shall visit the same country' (Thomson, 1880a, p. 103). Although this is interpretable as an instance of authorial modesty, a trope of self-effacement characteristic of many explorers' narratives (Keighren, Withers and Bell, 2015), it is certainly an admission of personal failure to master the instruments in question.

Explorer-authors were thus acutely aware of instrumental failure and breakdown, of the facts of error that underlay their use of instruments. They were, in different ways, themselves measured by their use of instruments, that is, in the connotations between instrument use and exploratory and authorial credibility. For Gooday, measurement is freighted with moral

significance in several ways: 'in the *presupposition* of a measurement; what was fair to assume about the integrity of previous measurers in the field? In the *performance* of a measurement; did its conduct instantiate trustworthy practices and appropriate experimental virtues? In the *reporting* of a measurement; was the written (published) account an honest and impartial summary of the performance? And in the *ramifications* of a measurement; what benefits – if any – might the quantitative information generated bring to others?' (Gooday, 2004, p. xvi, original emphasis). It is in studying, then, what Gooday terms 'these sorts of quotidian issues in the *practice* of measurement' (Gooday, 2004, p. 15) that we are afforded insight into how instruments work and the bases to the trust placed in their results and in their users. The epistemological bases to trust rest not alone, or even principally, in the status of the observer (*cf*. Shapin, 1994, 2004), but 'in the appropriateness of an instrument, technique, or materials for achieving a particular kind of measurement in a given context' (Gooday, 2004, p. 21) – that is, as Baird emphasises, in the work of instruments.

The experiences of those explorers listed in MS AP 52 speak variably to Gooday's distinctions. O'Neill's remarks highlight the moral value associated with multiple observations, an aggregative instrumental performance. Comber twice justified his own conduct, and his instruments' readings, by casting doubt on the integrity of others' work even though, as noted, he had damaged his own half-chronometer: on a Lieutenant Grandy for erroneous latitude observations and 'ill-calculated dead reckoning'; of Henry Morton Stanley for errors in estimating the extent of Stanley Pool on the Congo (Comber, 1881, p. 21; 1884). Stewart had occasion to correct Livingstone's instrumental readings, even as he admitted to being of a 'humbler class of explorers'.[14] The ramifications of using instruments of measurement in exploration and in arguing from what they 'told' one as an explorer lay not just in positioning one's self – topographically and morally – but in correcting others and, simultaneously, extolling one's own 'greater accuracy'.

Exploration narratives, semantic ascent, and the (in)visibility of instruments

Joseph Thomson was not able to use instruments properly despite pre-exploration training, but in the field, and, later and elsewhere in print, his instruments and their results were put to work for him. Thomson's report of April 1880 upon the progress of his East African Expedition cited instrument readings taken in situ by James Stewart, then exploring Lake Nyassa (Table I), 'my fever making me unfit for any work' (Thomson, 1880b, p. 211). In London, Thomson's readings and such devices as returned (see Table I) were scrutinised by John Coles. Thomson's credibility depended not only upon which instruments he had used but also upon the relative status of his readings vis-à-vis other explorers. 'The thermometers Nos. 15007 and 15111 are not known to me' [reported Coles – that is, they were not RGS instruments] 'and as they give widely different results from the other two thermometers (which I have corrected for the error given in the Kew certificates), it is probable that they have some error, without the knowledge of which it would be impossible to obtain true results'. Thomson's results 'most nearly coincide with those of Dr. Livingstone, and differ most from those of Mr. Stanley'.[15]

Coles worked thus with several others in validating in situ instrumental work from his position of authoritative instruction. James Stewart sent longitude readings taken on his 1880 exploration to the RGS in advance of his return – 'in order . . . that they may be re-calculated and recorded'– admitting, too, that owing to 'the absence of good landmarks on the Mambwe plateau, I cannot place much reliance on the route-survey', that is, upon his own in situ observations (Stewart and Coles, 1880, p. 431). Coles computed Stewart's longitudinal results using three different methods, rejected one set of results from the final published report, and compared, as had Stewart, his results with those of Stanley and Livingstone.[16] As the editor of the RGS's *Proceedings* noted in a footnote, yet further amendment of the

instrument results took place in preparing the map of Stewart's exploration for publication (Stewart and Coles, 1880, p. 431). In print, Stewart later made these processes clear:

> These days were spent with Mr. Thomson, and the nights in great measure with my sextant and note-book. After a good deal of labour, I at last succeeded in taking a set of lunar observations, which satisfied myself at the time, and on the accuracy of which I had the pleasure of being complimented by Mr. Coles after my return to this country. The result of these observations is to fix the longitude of Pambete at 31° 21′ 20″ E. This result is a very good mean between the positions assigned to Pambete by Messrs. Stanley and Thomson, and may, I believe, be accepted as approximately accurate (Stewart, 1881, p. 271).

In private, Stewart admitted that he petitioned one of his referees, Africanist James Augustus Grant, to be allowed to 'tip in' to the work lengthy tables of astronomical observations, even offering to pay for their typesetting: Grant wrote to Henry Bates, RGS Secretary, to lend his support.[17]

Such evidence extends our understanding of exploration narratives as the product of cumulative authorship. Instruments were at work yet (in)visible in different ways. For Comber, instrument use evinced greater trust in one's self than in 'previous measurers in the field' (to use Gooday's words). The performance of the device in his hands, not others', and the results produced had value, expressed as 'greater accuracy', 'more precise measurement', and so on. Such value was enhanced if instrument readings were supplemented by computation designed to reduce error, as was the case for Stewart and Thomson. Their work of 1881 was refereed together in order to ensure comparability of result between the two men, James Augustus Grant seeing the work by the missionary (Stewart) and the geographer

(Thomson) as joint means 'to dissipate that uncertainty' over Africa's interior.[18] Forbes did not use instruments. O'Neill did, to great effect, large numbers of readings compensating (he hoped) for admitted failures in accuracy.

While the emphasis in these exploration narratives is upon the activities of the explorer, upon *what* was achieved, each of the twenty published papers in which instruments are mentioned by the explorer-authors in Table I makes clear the explorer's dependence upon instruments in *how* exploration was undertaken. There were differences in what is said about the role of instruments, the extent to which explorer-authors documented the working of the devices or focused upon the results produced and their implications. The notion of semantic ascent as the primacy of words over the work of instruments thus disguises complex circumstances. Some texts depended for their credibility not just upon instruments at work, but also upon the circulation of instrumental readings corrected elsewhere. Some users accepted error in the use of instruments even as they asserted 'truth' claims about the results. The ramification of measurement could depend upon its later corroboration elsewhere by others.

O'Neill's texts and instrument work illustrate these complexities well. Unlike Thomson, O'Neill was fastidious in his use of instruments and in accumulating sets of instrumentally-derived observations. Like Stewart, he sent his instrumental observations and other materials (his diary and topographical sketches) to the RGS that others could prepare the map and publication. In review, Grant regarded O'Neill's work as 'thoroughly reliable', in contrast to that of W. P. Johnston (see Table I), about whom Grant was less complimentary.[19] In laying down O'Neill's route, cartographer and population geographer Ernst Georg Ravenstein reported that, 'we have adopted the whole of his observed latitudes'. Further, 'All longitudes, up to Shalawe, and all those beyond, being the means of lunars [that is, taken by the sextant] and chronometer observations (Mkuburo alone excepted), have been adopted'. One

settlement's longitude, however, 'derived from no less than 45 sets of lunars, unfortunately reached us too late to be utilised in the compilation of the map'. The implications of this omission were profound: 'The adoption of the longitude resulting from these lunars would necessitate the rejection of all observations for longitude to the northward and westward of it, and would have completely deranged the topographical features of the country, as they appear upon Mr. O'Neill's own sketches. . . . The present map must be considered, therefore, as provisional only'.[20]

In Africa, O'Neill was unable for two reasons to fix longitudinal positions with accuracy, despite taking 2000 separate observations: the fragility of his chronometers, and the lack of a standard reference point from which his measurements might be calibrated. As he reported, travellers' chronometers 'have been jolted upon the heads of blacks, subjected when on the march to very high temperatures under an almost vertical sun; subjected also to different degrees of atmospheric pressure'. This mattered because the instruments had been rated elsewhere:

> These chronometers, . . . have been carefully rated on the coast and their errors on Greenwich mean time and rates obtained at some well-determined point. But it is in the highest degree improbable that, under such varying and unfavourable conditions, they have preserved their rates undisturbed, and consequently, before the traveller has even arrived upon the field he is intending to explore, his error on Greenwich mean time is in fault, and therefore, of course, his observations for longitude (O'Neill, 1885, p. 434).

O'Neill's attempts (unsuccessful) to have Blantyre classed as a 'secondary meridian' in relation to the prime meridian, unconnected as it was to Greenwich which had been proposed

as the world's base point only one year earlier (Withers, 2017), depended upon astronomical observations whose accuracy he had good reason to question.[21]

4 | CONCLUSION: OBJECT LESSONS – THE IMPLICATIONS OF INSTRUMENT EPISTEMOLOGY

Instruments, and their proper use, were crucial elements in guides to exploration (Jackson, 1841; Herschel, 1849) and in the emergence of method in science and geography (Driver, 1998; Withers, 2013; Wess and Withers, 2018). What is revealed here is the fact of instruments at work and their resultant 'traces', in print and in manuscript. From the evidence of MS AP 52, we can now better understand the place of 'things at work' in the doing of exploration and the making of narrative – the mutual constitution of words and the meaningful action of things, scientific instruments, as beyond mute objects (Daston, 2004).

Foregrounding the work of instruments as 'thing knowledge' – Daston's claim to objects' material 'self-evidence: *res ipsa loquitur*, the thing speaks for itself' (Daston, 2004, p. 12) – requires attention to how words characterise what instruments do. Insights into instrument epistemology – the work of instruments – are in that sense consequential upon authors' preparedness not just to admit to use of instruments, but to recount the work performed and, on occasion, to admit to failure – of themselves, other explorer-authors, and the devices themselves. In the field, not all instruments worked as they should. Not all returned (instruments or individuals). Instrumentally-derived results in the field were mobilised, sometimes in advance of their authors' return, to be corroborated by others elsewhere. One of the methodological challenges of the field sciences, unlike the regulatory cultures of the laboratory, is the achievement of accuracy or of distant authors' claims to it (Boumans, 2015). For several explorers, inaccuracy, or, at least, recognition of the provisional nature of the results generated – a consequence of operator error and failure in the instrument – was

tolerated. Instrumental measurement was a moral project, in its performance, ramifications, and reportage given admission, or not, over the facts of failure and its moral consequences.

The wider implications are several. Scientists, geographers included, are commonly trained 'to present their findings as phenomena or data rather than as the products of artifacts and instruments' (Gooding, Pinch and Schaffer, 1989, p. 15). This paper has pointed to the possibilities for placing instruments more centrally in narratives of exploration and as objects for attention in their own right. Baird's notion of semantic ascent, superficially attractive in describing the primacy of words, must be examined on a case-by-case basis in relation to the different instruments and processes through which text was produced. Geography's history – which, in Britain at least, accords considerable authority to exploration in the nineteenth century (Driver, 2001; Wess, 2017) – would be enriched through closer attention to matters of performance and practice, to how and where text was assembled, and to the shortcomings of instruments and authors. Failure – pervasive in one form or another in instruments' use in exploration – is not the simple opposite of success, nor a simple matter of technical breakdown. Failure is always relational, and is moral as much as it is material (Carroll, et al, 2017). Precisely because 'things' did not work as their operators wanted or expected them to suggests there is more to know yet about 'thing knowledge', the complexities of instruments' use, and how that use was reported in words in exploration.

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[1] RGS (with IBG), Scientific Purposes Committee Minutes, 16 June 1879.

[2] RGS (with IBG), Council minutes, 9 and 16 June 1879.

[3] RGS (with IBG), Correspondence Block 6 1871–1880, John Coles, 31 July 1879.

[4] RGS (with IBG), Correspondence Block 6 1871–1880, John Coles, 'Report of Instruction given from January 22nd to April 16th 1880', 26 April 1880. In one respect, Coles' enumeration is in error: no missionary in this list was at work in China. The individual supported in his China work was Archibald Ross Colquhoun whose book documents his surveying and promotion of Britain's commercial interests in Indo-China (Colquhoun, 1883).

[5] RGS (with IBG), Expedition Committee Minutes, 16 November and 8 December 1882.

[6] RGS (with IBG), Special Purposes Committee 16 June 1879; MS AP/51.

[7] RGS (with IBG), Catalogue of Instruments: Joseph Thomson, for example, borrowed instruments on 9 May 1881, 13 December 1882, 28 January 1885 and 6 March 1888.

[8] RGS (with IBG), Catalogue of Instruments, p. 43, Number 3.

[9] RGS (with IBG), Catalogue of Instruments, p. 77, Number 10.

[10] RGS (with IBG), Special Purposes Committee, 12 November 1880 (Dr. Southon); Committee Minutes 13 December 1880 (Colonel Yule), and 16 January 1882 (Lord Mayo).

[11] RGS (with IBG), Correspondence Block CB 6, Henry Forbes [to Henry Bates, RGS], 15 April 1879.

[12] RGS (with IBG), JMS 8/64. As Wess shows, this refusal by Forbes to work with instruments, despite being provided with them by the RGS, was at odds with his recognition of their importance in scientific measurement, as Forbes showed in discussing the seismometry of the 1883 Krakatoa eruption (Wess, 2017, 178).

[13] RGS (with IBG), JMS 2/238 [Comber's note on his laxness appears in this referee's file, dated April 1885]. Comber's letters to Coles and to RGS Secretary Henry Walter Bates asking for instruments from the Society are: Correspondence Block CB6, 26 February 1879; 14 April 1880.

[14] RGS (with IBG), JMS /2/196, f.2.

[15] Coles' comments appear, printed, as 'Note on Mr. Thomson's hypsometrical observations, by Mr. J. Coles, Map Curator, R.G.S' appended to Thomson (1880b).

[16] Coles' corrections and his comparison of longitudinal observations taken by Stewart and others appears, printed, as 'Note on the lunar distances, observed by Mr. James Stewart at Pambete, November 9th, 1879' appended to Thomson and Coles (1880).

[17] RGS (with IBG), JMS 2/244, Letter from O'Neill to Grant 22 May 1885.

[18] RGS (with IBG), JMS 2/212. Grant is here reviewing Stewart's work on Lake Nyassa: 10 March 1879.

[19] RGS (with IBG), JMS 2/233; Grant's referee's report is dated 8 December 1884. In it, he invites the Revd. Johnston to respond to the queries raised: no response was forthcoming.

[20] Ravenstein's comments appear, printed, appended to O'Neill (1884, p. 713).

[21] RGS (with IBG), Committee Minutes, 14 December 1885; (Wess, 2017, 202-3).